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GENERAL BIOPHYSICAL INVESTIGATION AND INSTRUMENTATION

FINAL REPORT

ON

TASK IV

"Measurement of Intracardiac and
Intravascular Blood Velocity"

FOR

Physiology Branch
OFFICE OF NAVAL RESEARCH
Washington 25, D.C.

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FINAL REPORT
ON
ULTRASONIC FLOWMETER - NONR 2912(00)

I. INTRODUCTION

In diagnosing cardiovascular diseases, the diagnostician desires to avail himself of all the information which can be obtained within the state of the art of medical instrumentation. It is the function of the physiologist studying the circulatory system to provide an understanding of its functioning so that the diagnostician may utilize this knowledge in making accurate diagnoses. One circulatory parameter which is of great interest is the actual velocity of the blood or more specifically the mass flow rate. This may be defined as the amount of blood passing a given point in a given time. Such a measurement could, for example, be used to determine cardiac output.

For many years the only technique available to measure blood flow was a dye technique in which dye was injected at one point in the blood stream and its time of arrival at another point, a fixed distance from the first, was measured. This technique provided at best, only information as to the average speed of the blood which, in itself, is not very useful.

In order to overcome the inadequacies of this technique several electrical devices were developed. The only such device to become commercially available utilized the fact that the blood stream is essentially a moving conductor. By producing a magnetic-field perpendicular to the direction of blood flow, a voltage is induced in the blood which can be measured. Since, the

magnetic field strength, length of "conductor", etc. are known, the blood velocity may be obtained.

Another approach to the problem, which is still in the development stage, is an ultrasonic technique. Articles have appeared in the literature which describe a device consisting of two barium titanate transducers placed diagonally opposing along the outside of the vessel. Sound is then transmitted from one crystal to the other, first in one direction and then in the opposite direction. The time difference between the time of arrival of the sound at one transducer and that at the second, which arises from the fact that the sound has passed through a moving medium, is a measurement of the blood velocity. (For a more detailed explanation, see Part II of this report).

A major disadvantage of the two techniques mentioned above is the fact that surgery must be performed in order to place them around the blood vessel. In doing this surrounding tissues must be removed and hence the external environment of the vessel is disturbed. Furthermore, surgery, particularly thoracic surgery, is time consuming, costly and dangerous.

A solution to these problems is provided by the approach which is discussed below; i.e. a catheter mounted flowmeter. Such a device would allow access to the major vessels of the body with relatively little risk and with an absolute minimum of surgical procedure.

II. THEORY OF OPERATION

Consider two transducers placed in a medium which is moving toward the right with a velocity designated by v_m . The transducers are so arranged that they are in line with each other and the axis joining them is parallel to the direction of v_m . Their separation is denoted by d . (See Figure 1).

Let v_s represent the velocity of sound in the medium when it is stationary. If transducer 1 is now caused to emit a pulse of sound, this pulse will be received by transducer 2 after a time given by:

$$(1) \quad t_{12} = \frac{d}{v_s + v_m}$$

If now transducer 2 emits the sound pulse and transducer 1 acts as the receiver, the time is given by:

$$(2) \quad t_{21} = \frac{d}{v_s - v_m}$$

Subtracting these time intervals we have

$$(3) \quad \Delta t = t_{21} - t_{12} = \frac{d}{v_s - v_m} - \frac{d}{v_s + v_m}$$

$$(4) \quad \Delta t = \frac{2v_m d}{v_s^2 - v_m^2} \quad \text{if } v_s \gg v_m \quad \text{then}$$

$$(5) \quad \Delta t = \frac{2v_m d}{v_s^2}$$

$$(6) \quad v_m = \frac{v_s^2}{2d} (\Delta t) \quad \text{or}$$

If Δt can be measured, v_m can be calculated since v_s is a constant of the medium and d is fixed.

III. DESIGN CONSIDERATIONS

Two basic systems present themselves for measuring Δt . Either the phase shift of two CW signals caused by the time delay or the time delay between the reception of pulses at one transducer and at the other may be measured. In order to get a feel for these quantities it is helpful to perform some simple calculations.

Referring to Equation (5), let $d = 1$ cm, $v_m = 1.5 \times 10^5$ cm/sec and $v_s = 10^6$ cm/sec.

$$\text{then } \Delta t = \frac{2(10)(1)}{(1.5 \times 10^5)^2} = .89 \times 10^{-9} \text{ sec.}$$

Using the general relationship that $\delta = 2\pi f \frac{d}{v}$

where δ = phase angle

f = frequency of sound

d = separation of transducers

and v = velocity of sound

we can derive the following expression using the same reasoning as employed in arriving at Equation (6):

$$(7) \quad \Delta \delta = 4\pi f \frac{dv_m}{v_s^2}$$

Assuming the same values for d , v_m , and v_s as used previously and in addition that $f = 10^6$ cps we obtain:

$$\Delta \delta = 4(3.14)(10^6) \frac{(1)}{(1.5 \times 10^5)^2} \frac{(10)}{2}$$

$$\Delta \delta = 5.6 \times 10^{-3} \text{ rad}$$

$$\Delta \delta = .321^\circ \text{ (electrical degrees)}$$

The problem resolves itself into either the measurement of tenths of nanoseconds or tenths of degrees. After investigating available instruments and circuits, it was decided to measure the time difference rather than the phase difference since instabilities in the required electronic circuitry would make it extremely difficult to obtain the necessary precision. Accordingly, a circuit similar to that used by Franklin et al has been constructed.

A brief explanation of the functioning of the circuits is as follows. The synchronizing circuits (SYNC CIRCUITS) produce a 400 cps sine wave and an 800 pps signal. The 400 cps signal drives the CHOPPER DRIVER which in turn drives the choppers at a rate of 400 cps, while the 800 pps signal is used to trigger the transmitter, gate the receiver, and reset the peak detector. The transmitter applies a 700V pulse to that crystal which is serving as the acoustic source. It also triggers a bi-stable multivibrator. The signal received by the crystal which is acting as the receiver is amplified and that portion of the signal which passes through the gate, triggers (stops) the bi-stable multivibrator. The received transient signal in passing through the receiver is clipped and limited so that it is the first negative half cycle which is responsible for flopping the multivibrator. The output of the multivibrator drives a gated ramp generator with a slope of approximately $20^{mv}/10^{-9}$ sec., which is fed into a peak detecting circuit. The resulting output signal is an amplitude modulated 400 cps signal which carries the necessary information. This information can be extracted as a varying dc voltage which is proportional to transit time. Using Equation (5) blood velocity can be determined since it is directly proportional to the transit time.¹

Two barium titanate transducers having a resonant frequency of approximately 3 megacycles were chosen after consideration had been given to the following facts: (1) the ultrasonic beam angle should be as small as possible, which implies a high operating frequency; (2) diffraction effects must be kept to a minimum; and, (3) attenuation of the sound in blood increases with frequency.

The housing for the transducer has been designed and a drawing of it appears as Figure 2. The one centimeter spacing of the crystals should allow the blood to flow between the transducers without disturbance. Placing the crystals farther apart requires greater acoustic power for transmission, increases the difficulty of insertion, increases the chance of breakage due to torque, and presents increased difficulties in getting the catheter around bends in the circulatory system. A No. 9 French catheter is considered to be the largest practical cardiac catheter.

IV. RESULTS

The actual construction of the flowmeter catheter and the associated electronic circuitry has been completed. In vitro tests indicate that the electronic circuitry is functioning as expected, although some modifications will be necessary in the actual transducer tip to make the system compatible.

V. FUTURE PLANS

1. Modify the transducer tip so that it is compatible with the electronics and the intended mode of operation.
2. Provide a read-out for the electronic circuitry in the form of chart recordings.

REFERENCES

1. Franklin, et al, "Pulsed Ultrasonic Transit Time Flowmeter," IRE Trans. on Bio-Medical Electronics, Vol. BME-9, Jan. 1962 p.44.